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Use of Lung Ultrasound for Assessment of Lung Recruitment Maneuvers in Patients with ARDS

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Abstract

BACKGROUND: Positive pressure mechanical ventilation is a non-physiological intervention that saves lives but is not free of important side effects. It invariably results in different degrees of collapse of small airways. Recruitment maneuver (RM) aims to resolve lung collapse by a brief and controlled increment in airway pressure while positive end-expiratory pressure (PEEP) afterward keeps the lungs open. Therefore, ideally RM and PEEP selection must be individualized and this can only be done when guided by specific monitoring tools since lung's opening and closing pressures vary among patients with different lung conditions.

AIM: The aim of this study was to explore the clinical value of ultrasonic monitoring in the assessment of pulmonary recruitment and the best PEEP.

PATIENTS AND METHODS: This study was conducted on 120 patients, 30 were excluded as in whom lung collapse cannot be confirmed then the rest were 90 patients from whom another 25 patients excluded as they were hemodynamically unstable the rest 65 patients were divided into two groups: Group A: Included 50 mechanically ventilated patients with ARDS, underwent lung recruitment using lung ultrasound and Group B: Included 15 mechanically ventilated patients with ARDS, underwent lung recruitment using oxygenation index. This prospective study was held at many critical care departments around Egypt.

RESULTS: We noticed that lung recruitment in both groups significantly increased Pao2/Fio2 ratio immediately after recruitment compared with basal state and also significantly increase dynamic compliance compared with basal state. The increase in PF ratio immediately was significantly more in ultrasound group than in oxygenation group. Furthermore, we noticed that that P/F ratio 12 h after recruitment decreased compared with P/F ratio immediately after recruitment but significantly increased compared with basal state before recruitment and also we found that the increase in P/F ratio 12 h after recruitment was more significantly in lung ultrasound group than in oxygenation group. Furthermore, we noticed that lung recruitment (both lung ultrasound and oxygenation group) significantly increase RV function using TAPSE compared with basal state. Both opening pressure and optimal PEEP were significantly higher in lung ultrasound group than in oxygenation group. In our study, opening pressure was 37.28 ± 1.25 in lung ultrasound group and was 36.67±0.98 in oxygenation group and optimal PEEP was 14.64 ± 1.08 in lung ultrasound group and was 13.13 ± 0.74 in oxygenation group.

CONCLUSION: Lung US is an effective mean of evaluating and guiding alveolar recruitment in ARDS. Compared with the maximal oxygenation–guided method, the protocol for reaeration in US-guided lung recruitment achieved a higher opening pressure, resulted in greater improvements in lung aeration, and substantially reduced lung heterogeneity in ARDS.

Introduction

Knowing the positive end-expiratory pressure (PEEP) helps in the treatment of acute respiratory distress syndrome (ARDS), which is associated with a significant risk of mortality [1], [2].

Methods used to evaluate the effect of PEEP-induced pulmonary recruitment include computed tomography (CT), the static pressure–volume (P–V) curve, and the oxygenation method [3], [4], [5].

However, the uses of these methods are limited due to objective factors. For example, for lung CT examination, critically ill patients must be transported out of the intensive care unit (ICU), which carries risk of transfer, high cost, and radiation exposure [6], [7], [8].

Static P–V curve tracing requires deep sedation and muscle relaxation. The oxygenation method is the most commonly used in clinics, but it is necessary to repeat arterial blood collection many times, which is cumbersome and expensive. An ultrasonic examination is noninvasive, convenient, and reproducible. Due to the low water content, normal lung tissue cannot be detected by an ultrasonic examination; however, abnormal lung tissue has obvious changes in the gas/water ratio, which can be observed by the ultrasonic method. Studies have been evolving the value of ultrasound in the evaluation of lung recruitment [9], [10].

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Aim of the work

The aim of this study was to explore the clinical value of ultrasonic monitoring in the assessment of pulmonary recruitment and the best PEEP.

Patients and Methods

This study was conducted as a non-randomized interventional prospective study on 65 patients between February 2017 and April 2019 in multicenter.

Inclusion criteria

Mechanically ventilated patients with ARDS with confirmed lung collapse were included in the study.

Exclusion criteria

The following criteria were excluded from the study:

- Mechanically ventilated patients not suffering from lung collapse and not needing lung recruitment maneuvers (RM)
- Mechanically ventilated patients who are hemodynamically unstable.

Study groups

This study included 65 patients divided into two groups:

Group A

Included 50 mechanically ventilated, who underwent lung recruitment using lung ultrasound.

Group B

Included 15 mechanically ventilated patients who underwent lung recruitment using oxygenation index.

ARDS in our study was identified using Berlin definition [11]

1. Acute onset over 1 week or less
2. bilateral opacities consistent with pulmonary edema must be present and may be detected on CT or chest radiograph
3. PF ratio <300 mmHg with a minimum of 5 cmH20 PEEP (or CPAP)
4. "Must not be fully explained by cardiac failure or fluid overload," in the physician's best estimation using available information — an "objective assessment" (e.g. echocardiogram) should be performed in most cases if there is no clear cause such as trauma or sepsis.

All studied patients were subjected to

Clinical assessment

- History taking (age, DM, hypertension, COPD, and steroid use)
- Physical examination: Include general examination (including blood pressure, heart rate, temperature and respiratory rate) and local examination.

Laboratory assessment

CBC, kidney function tests (serum creatinine and serum urea), and serum electrolyte (serum sodium and potassium) and arterial blood gases.

Imaging

- Chest X-ray
  Using 4 quadrant score.
- Echocardiography

We assessed IVC diameter and RV functions using TAPSE.

- Lung ultrasound

We used lung ultrasound to determine the need for RM in each patient answering is whether our patient needs a RM. Ultrasound can detect the presence of lung collapse predominantly in dependent (dorsal) pulmonary areas following the gravity vector. Lung collapse can manifest as slight to moderated loss of lung aeration (from isolated to coalescent B-lines) up to complete atelectasis (sub-pleural consolidations with static air-bronchograms).

Preparation

- Correction of hypovolemia and keeping mean arterial pressure (MAP) more than 75 mmHG using IV fluids and inotropes if needed
- Adjustment of respiratory rate to 35 rpm for 20 min before recruitment
- Sedation and neuromuscular blockade
- Keeping patient in supine or prone position
- Aspiration of lower airways secretions
- Increasing FIO2 to 1.0
- Increase airway pressure limit to 60 cmH2O and PEEP alarm limit to 40 cm H_2O
- Decreases trigger sensitivity
- Change to pressure control ventilation. set pressure to 20 cm H2O above PEEP, I: E 1:1, RR 15
- Then start recruitment.

Lung recruitment

We divided patients two groups.

Group A

First, standard lung ultrasound scan was performed using different probes whose selection will depend on patient's age and body constitution as well as the clinical scenario. After performing a standard lung ultrasound scan, the selected probe is placed in the most dependent zone of the atelectatic lung. The RM maneuver is started searching the pressure level at which the consolidation-pattern disappears and progressive lung re-aeration is observed. Re-aeration usually follows a sequential pattern: Condensation — B2 lines — B1 lines to normal lung images but, sometimes, the pattern of condensation is transformed directly in a normal pattern. Then, the probe is placed in the same position in the contralateral lung and if a normal aeration is confirmed, this level of airway pressure is defined as the lung's opening pressure. After lung recruitment, it is necessary to perform a step-wise decrement in PEEP (PEEP trial) to detect the lung's closing pressure. The very moment when normal lung aeration images transform into a B1–B2 pattern and consolidation pattern will define the closing pressure. The final selected level of PEEP is chosen to be 2 cm H2O above the detected closing pressure. Once the patient's opening and closing pressures are known, a new RM is performed reaching these target pressures and the identified PEEP level is set for ongoing ventilation.

Group B

We increase PEEP to 25 cm H2O for 10 breaths then decrease back to 20 cm H2O then increase PEEP to 30 cm H2O for 10 breaths then decrease back to 20 cm H2O then increase to 36 cm H2O in some patients and 38 cm H2O in others for 10 breaths then back to 20 cmH2O then decrease PEEP in steps 1 cm H2O until PaO2 starts to fall. Then, we repeated recruitment and set PEEP 2 cm H2O above previously noted value.

After lung recruitment

- Reset alarm limits and reset I; E ratio to 1:2
- We assessed effect of lung recruitment on heart rate and mean arterial blood pressures (MAP)
- We measured P/F ratio immediately after recruitment and 12 h after recruitment
- We assessed compliance immediately after recruitment
- We assessed RV function by TAPSE using echocardiography
- We calculate ultrasound reaeration score in Group A (Table 1). (score more than 9 means that recruitment is good).
- We did chest X-ray again 2 days after recruitment using 4 quadrant score.

Ethical considerations

Informed consent for participation in the study was obtained according to the guidelines of the institutional review boards for human subjects at the participating study centers.

Table 1: Ultrasound reaeration score

1 point	3 points	5 points
B1>N B2>B1 C>B2	B2>N C>B1	C>N

B1: Multiple well-defined either regularly spaced 7-mm apart or irregularly spaced B lines (moderate loss of lung aeration); B2: Multiple coalescent B lines (severe loss of lung aeration); C: Lung consolidation; N: Normal pattern (normal lung aeration). *The ultrasound reaeration score was calculated as follows: In a first step, ultrasound lung aeration (N, B1, B2, and C) was assessed in each of the 12 lung regions examined before and after application of PEEP. In a second step, ultrasound lung reaeration score was calculated as the sum of each score characterizing each lung region examined according to the scale shown in the table. Increasing aeration score less than 8 means bad ineffective recruitment and further trials in future not recommended.

AQ5

Statistical analysis

Data were coded and entered using the statistical package SPSS version 25. Data were summarized using mean, standard deviation, median, minimum and maximum in quantitative variables and frequencies (number of cases) and relative frequencies (percentages) for categorical variables. Comparisons between groups were done using unpaired t-test in normally distributed quantitative variables while non-parametric Mann–Whitney test was used for non-normally distributed quantitative variables. For comparison of serial measurements within each patient paired, t test was used. For comparing categorical data, Chi-square ($\chi 2$) test was performed. Exact test was used instead when the expected frequency is less than 5. $p < 0.05$ was considered as statistically significant.

Results

This study was conducted on 120 patients, 30 were excluded as in whom lung collapse cannot be confirmed then the rest were 90 patients from whom another 25 patients excluded as they were hemodynamically unstable the rest 65 patients were divided into two groups:

- Group A: Included 50 mechanically ventilated patients with ARDS, underwent lung recruitment using lung ultrasound
- Group B: Included 15 mechanically ventilated patients with ARDS, underwent lung recruitment using oxygenation index.

This Prospective study was held at many critical care departments around Egypt.

Description of all studied patients

Our study included 65 patients whose were 35 male (53.8%) and 30 females (46.2%) with mean age 52.74 ± 21.23 with mean of APACHE II 18.63 ± 6.58.

24 patients from studied population were diabetic while 41 were not diabetic and 21 were hypertensive while 44 were not hypertensive and 9 were COPD and 56 were not COPD.

28 patients from studied patients were mechanically ventilated due to pneumonia, eight patients due to massive blood transfusion after severe bleeding, eight patients due to sepsis, five patients due to RTA, five patients due to aspiration of gastric contents, three patients due to organophosphorus poisoning, three patients due to acute pancreatitis, two patients due to smoke inhalation, two patients due to postoperative, and one patient due to near drowning.

Demographic data of the studied population (Tables 2 and 3)

- Group A: Included 50 mechanically ventilated patients with ARDS, hemodynamically stable, with confirmed lung collapse of whom 26 were males and 24 were females with mean age (52.4 ± 21.35)
- Group B: Included 15 mechanically ventilated patients with ARDS, hemodynamically stable with confirmed lung collapse of whom nine were males and six were females with mean age (53.87 ± 21.51).

There was no statistically significant difference between Groups A and B regarding demographic data.

Table 2: Gender of studied populations

	Method of lung recruitment				p-value
	Group A		Group B		
	Count	%	Count	%	
Gender					
Male	26	52.0	9	60.0	0.586
Female	24	48.0	6	40.0	

Clinical data of the studied population (Tables 4 and 5)

Group A

Regarding medical history, 20 patients were diabetic, 15 patients were hypertensive, and eight patient were COPD, with mean APACHE (18.16 ± 6.36).

Group B

Regarding medical history, four patients were diabetic, six patient were hypertensive, and one patient was COPD, with mean APACHE (20.20 ± 7.30).

The both group were compared that revealed a no statistically significant difference between group as regard associated comorbid conditions, nor admission APACHEII score.

Laboratory data (Table 6)

Group A

The mean HB was 10.46 ± 2, the mean WBCs was 18650 ± 7553, the mean platelets 188300 ± 92805, the median of serum creatinine 1.6 with minimum 0.9 and maximum 11.8, the mean of serum Na was 135.24 ± 5, and the mean of serum K was 4.4 ± 0.79.

Group B

The mean of HB was 10.79 ± 2.4, the mean of WBCs was 21066.67 ± 9587.69, the mean of platelets was 156200 ± 57701.45, the mean of serum creatinine was 1.93 ± 0.58, the mean of serum Na was 136.07 ± 5.3, and the mean of serum K was 4.68 ± 0.74.

There was no statistically significant difference between both groups as regard admission laboratory data.

Mechanical ventilation (Table 7)

Group A

Regarding cause of MV (21 patients) 42% was pneumonia, (6 patients) 12% was sepsis, (6 patients) 12% was severe bleeding with massive blood transfusion, 8% (4 patients) RTA, 8% (4 patients) aspiration of gastric contents, and 4% (2 patients) for every one of the following, smoke inhalation, organophosphorus poisoning, acute pancreatitis, and post-operative and 2% (one patient) near drowning.

Regarding mode of ventilation 68% of patients was on volume controlled ventilation (VCV) and 32% were on pressure controlled ventilation (PCV) before lung recruitment.

Regarding steroid thereby 72% of patients had steroid therapy.

Table 3: Age of studied populations

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Age (years)	52.40	21.35	59.00	16.00	89.00	53.87	21.51	63.00	19.00	78.00	0.564

Table 4: Comorbid conditions of studied populations

	method of lung recruitment				p-value
	Group A		Group B		
	Count	%	Count	%	
DM					
Yes	20	40.0	4	26.7	0.348
No	30	60.0	11	73.3	
HTN					
Yes	15	30.0	6	40.0	0.535
No	35	70.0	9	60.0	
COPD					
Yes	8	16.0	1	6.7	0.672
No	42	84.0	14	93.3	

Group B

Regarding cause of MV 46.7% (7 patients) was pneumonia, 13.3% (2 patients) was sepsis, 13.3% (2 patients) was severe bleeding with massive blood transfusion, 6.7% (1 patient) for every one of following RTA, aspiration of gastric contents, organophosphorus poisoning, and acute pancreatitis.

Regarding mode of ventilation 66.7% of patients was on VCV and 33.3% was on PCV before lung recruitment.

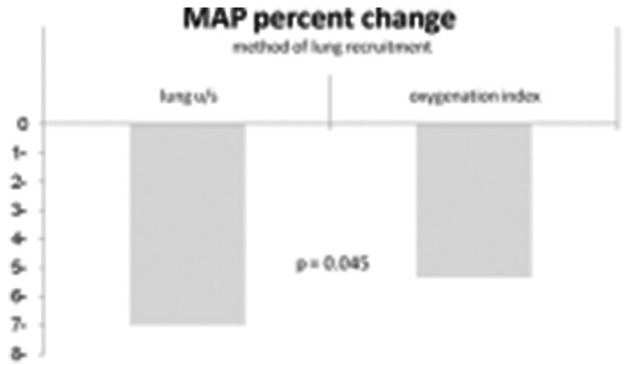

Figure 1: MAP percent change

Regarding steroid thereby 80% of patients had steroid thereby.

There was no statistically significant difference between both groups as regard causes of MV and mode of ventilation and steroid thereby.

Outcome of lung recruitment (Tables 8-10 and Figures 1 and 2)

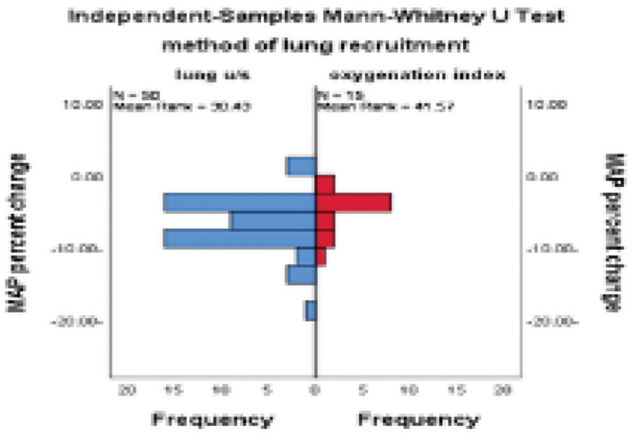

Figure 2: Independent-Samples Mann-Whitney test method of lung recruitment

Hemodynamics

Group A

The mean of heart rate before lung recruitment was 114.58 ± 14.03 and the mean of heart rate during lung recruitment was 124.52 ± 13.58 with statistically significant increase in heart rate during lung recruitment.

The mean of MAP was 100.02 ± 6.26 before lung recruitment and the mean of MAP during lung recruitment was 92.98 ± 6.17 with statistically significant decrease in MAP during lung recruitment.

Group B

The mean of heart rate before lung recruitment was 114.6 ± 7.47 and the mean of heart rate during lung recruitment was 121.87 ± 6.89 with statistically significant increase in heart rate during lung recruitment.

The mean of MAP was 99 ± 3.95 before lung recruitment and the mean of MAP during lung recruitment was 93.67 ± 3.37 with statistically significant decrease in MAP during lung recruitment.

There was statistically significant difference between both groups as regard MAP percent change before and during lung recruitment. In lung ultrasound group, the median of MAP percent change was -6.67 with maximum 0.00 and minimum -18.18 while in oxygenation index group the median of MAP percent

Table 5: APACHE score of studied populations

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
APACHE	18.16	6.36	17.00	10.00	36.00	20.20	7.30	19.00	12.00	33.00	0.296

Table 6: Admission laboratory data of studied populations

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
HB	10.46	2.00	10.40	7.00	15.00	10.79	2.46	11.00	5.50	15.00	0.606
WBCs	18650.00	7553.38	18000.00	3000.00	34000.00	21066.67	9587.69	21000.00	3000.00	41000.00	0.312
Platelets	188300.00	92805.54	177000.00	50000.00	550000.00	156200.00	57701.45	167000.00	76000.00	256000.00	0.211
Na	135.24	5.05	134.00	126.00	145.00	136.07	5.30	136.00	129.00	146.00	0.584
K	4.40	0.79	4.25	3.20	6.70	4.68	0.74	4.90	3.60	5.90	0.221
creat	1.90	1.55	1.60	0.90	11.80	1.93	0.58	1.80	1.30	3.30	0.151

change was –4.72 with maximum –2.08 and minimum –12.83 with (p-value 0.045).

P/F ratio immediate and 12 h after lung recruitment (Tables 11-13)

Table 7: Mechanical ventilation (cause, mode, and steroid therapy)

	Method of lung recruitment				p-value
	Group A		Group B		
	Count	%	Count	%	
Cause of ventilation					
Pneumonia	21	42.0	7	46.7	1
RTA	4	8.0	1	6.7	
Severe bleeding with massive blood transfusion	6	12.0	2	13.3	
Sepsis	6	12.0	2	13.3	
Smoke inhalation	2	4.0	0	0.0	
Organophosphorus poisoning	2	4.0	1	6.7	
Acute pancreatitis	2	4.0	1	6.7	
Aspiration of gastric contents	4	8.0	1	6.7	
Near drowning	1	2.0	0	0.0	
Post-operative	2	4.0	0	0.0	
Mode of vent					
VCV	34	68.0	10	66.7	1
PCV	16	32.0	5	33.3	
Steroids					
Yes	36	72.0	12	80.0	0.741
No	14	28.0	3	20.0	

Group A

The mean of Pao2/Fio2 ratio (PFR) before lung recruitment was 212.38 ± 61.90 and the mean of PFR immediate after lung recruitment was 398.36 ± 66.24 and the mean of PFR 12 h after lung recruitment was 345.32 ± 71.72 with statistically significant increase in both PFR immediate and 12 h after recruitment.

Group B

The mean of Pao2/Fio2 ratio (PFR) before lung recruitment was 218.78 ± 36.37 and the mean of PFR immediate after lung recruitment was 366.18 ± 53.21 and the mean of PFR 12 h after lung recruitment was 300.13 ± 55.34 with statistically significant increase in both PFR immediate and 12 h after recruitment.

There was statistically significant difference between both groups as regard PFR percent change before and immediate after lung recruitment. In lung ultrasound group, the mean of PFR percent change was 98.07 ± 46.19 while in oxygenation index group the

Table 8: Hemodynamic percent change regarding method of lung recruitment

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Pulse percent change	9.05	5.97	7.47	0.00	29.69	6.42	2.86	5.45	3.82	14.02	0.066
MAP percent change	–6.99	3.61	–6.67	–18.18	0.00	–5.34	2.67	–4.72	–12.38	–2.08	0.045

Table 9: Hemodynamics before and after recruitment in lung US group

Lung u/s	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Pulse	114.58	14.03	115.00	64.00	140.00	124.52	13.58	124.50	83.00	150.00	< 0.001
MAP	100.02	6.26	100.00	85.00	110.00	92.98	6.17	92.50	82.00	105.00	< 0.001

Table 10: Hemodynamics before and after recruitment in oxygenation index group

Oxygenation index	before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Pulse	114.60	7.47	114.00	105.00	131.00	121.87	6.89	122.00	111.00	136.00	< 0.001
MAP	99.00	3.95	99.00	94.00	106.00	93.67	3.37	93.00	90.00	101.00	< 0.001

Table 11: PFR before recruitment and immediate and 12 h after recruitment in lung US group

Lung u/s	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
PFR	212.38	61.90	221.50	82.00	299.00	396.38	66.24	401.00	233.00	490.00	< 0.001
PFR 12 h	212.38	61.90	221.50	82.00	299.00	345.32	71.72	337.00	149.00	456.00	< 0.001

Table 12: PFR before recruitment and immediate and 12 hrs after recruitment in oxygenation index group

Oxygenation index	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
PFR	218.73	36.37	222.00	150.00	284.00	366.13	53.21	391.00	276.00	432.00	< 0.001
PFR 12 h	218.73	36.37	222.00	150.00	284.00	300.13	55.34	300.00	212.00	400.00	< 0.001

Table 13: PFR percent change and PFR after 12 h percent change regarding method of recruitment

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
PFR percent change	98.07	46.19	76.71	49.44	240.91	68.57	15.90	63.02	47.89	101.01	0.009
PFR after 12 h percent change	69.95	33.02	61.44	16.54	177.27	37.85	18.31	32.83	14.59	93.47	< 0.001

mean of PFR percent change was 68.57 ± 15.90 with (p = 0.009).

There was statistically significant difference between both groups as regard PFR percent change before and 12 h after lung recruitment. In lung ultrasound group, the mean of PFR after 12 hrs percent change was 69.95 ± 33.02 while in oxygenation index group the mean of PFR after 12 h percent change was 37.85 ± 18.31 with (p < 0.001).

Compliance (Tables 14-16)

Group A

The mean of compliance before lung recruitment was 30.53 ± 2.72 and the mean of compliance after lung recruitment was 41.14 ± 4.94 with statistically significant increase in compliance after recruitment.

Group B

The mean of compliance before lung recruitment was 30.68 ± 3.13 and the mean of compliance after lung recruitment was 39.33 ± 3.85 with statistically significant increase in compliance after recruitment.

There was no statistically significant difference between both groups as regard compliance percent change before and after lung recruitment.

Right ventricular function using (TAPSE), (Tables 17-19 and Figure 3)

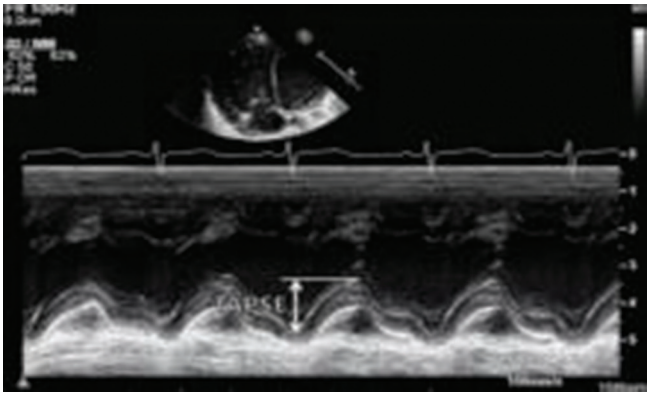

Figure 3: Right ventricular function using TAPSE

Table 14: Compliance before and after recruitment in lung US group

Lung u/s	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Compliance	30.68	3.13	31.00	22.00	36.00	41.14	4.94	43.00	27.00	48.00	< 0.001

Table 15: Compliance before and after recruitment in oxygenation index group

Oxygenation index	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Compliance	30.53	2.72	31.00	26.00	36.00	39.33	3.85	40.00	32.00	44.00	< 0.001

Table 16: Compliance percent change before and after recruitment regarding method

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Compliance percent change	34.35	12.62	34.38	12.50	62.96	28.90	7.54	29.03	17.24	44.83	0.145

Table 17: RV function before and after recruitment in lung US group

Lung u/s	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
RV	1.77	0.09	1.79	1.50	1.92	1.83	0.09	1.83	1.60	1.99	< 0.001

Table 18: RV function before and after recruitment in oxygenation index group

Oxygenation index	Before recruitment					After recruitment					p-value
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
RV	1.72	0.04	1.72	1.67	1.80	1.78	0.05	1.79	1.69	1.89	< 0.001

Table 19: RV function percent change before and after recruitment regarding method

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
RV percent change	3.32	2.32	2.93	-0.58-	9.04	3.44	1.72	3.39	0.56	6.78	0.607

Table 20: Opening pressure and optimal PEEP in both groups

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Opening pre	37.28	1.25	38.00	35.00	40.00	36.67	0.98	36.00	36.00	38.00	0.085
Optimal PEEP	14.64	1.08	15.00	11.00	16.00	13.13	0.74	13.00	12.00	14.00	< 0.001

Table 21: Day of recruitment and length of MV in both methods

	Method of lung recruitment										p-value
	Group A					Group B					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	
Day of MV	2.32	1.33	2.00	1.00	6.00	2.47	1.30	2.00	1.00	5.00	0.708
Day of recruitment	4.62	1.63	5.00	2.00	8.00	5.00	1.65	4.00	3.00	8.00	0.432
Length of ventilation (days)	9.60	2.71	9.50	5.00	16.00	11.27	4.57	10.00	7.00	25.00	0.236

Group A

The mean of RV function using TAPSE before lung recruitment was 1.77 ± 0.09 and the mean of RV using TAPSE after lung recruitment was 1.83 ± 0.09 with statistically significant increase in RV function after recruitment.

Group B

The mean of RV function using TAPSE before lung recruitment was 1.72 ± 0.04 and the mean of RV function using TAPSE after lung recruitment was 1.78 ± 0.05 with statistically significant increase in RV function after recruitment.

There was no statistically significant difference between both groups as regard RV function (using TAPSE) percent change before and after lung recruitment.

Opening pressure and optimal PEEP (Table 20 and Figure 4)

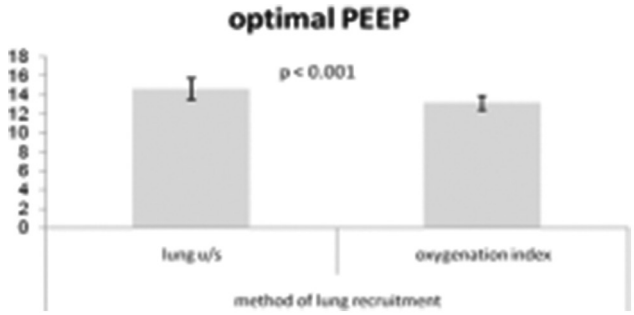

Figure 4: Optimal PEEP

Group A

The mean of opening pressure was 37.28 ± 1.25 and the mean of optimal PEEP was 14.64 ± 1.08.

Group B

The mean of opening pressure was 36.67 ± 0.98 and the mean of optimal PEEP was 13.13 ± 0.74.

There was statistically significant difference between both groups as regard optimal pressure with p < 0.001.

Day of recruitment and length of mechanical ventilation (Table 21)

Group A

The mean of day of recruitment was 4.62 ± 1.63 and the mean of length of MV was 9.6 ± 2.71.

Group B

The mean of day of recruitment was 5.00 ± 1.65 and the mean of length of MV was 11.27 ± 4.57.

There was no statistically significant difference between both groups as regard day of neither recruitment nor length of MV.

Complications (Table 22)

Group A

In lung US group, three patients out 50 developed complications in form of pneumothorax with 6% percent.

Table 22: Complication in both methods

	Method of lung recruitment				p-value
	Group A		Group B		
	Count	%	Count	%	
Complications					
Yes	3	6.0	2	13.3	0.325
No	47	94.0	13	86.7	
Mortality					
Yes	18	36.0	6	40.0	0.778
No	32	64.0	9	60.0	

Group B

In oxygenation index group, two patients out 15 had complications in form of pneumothorax with 13.3% percent.

There was no statistically significant difference between both groups as regard complication.

Mortality before hospital discharge (Table 23)

Group A

In lung US group, 18 patients out 50 died with percent 36%.

Table 23: Mortality in both groups

	Method of lung recruitment				p-value
	Group A		Group B		
	Count	%	Count	%	
Mortality					
Yes	18	36.0	6	40.0	0.778
No	32	64.0	9	60.0	

Group B

In oxygenation index group, six patients out 15 died with percent 40%.

There was no statistically significant difference between both groups as regard complication.

Discussion

The possibility of exploring the lung using ultrasound, at the bedside and noninvasively, is gaining popularity among intensivists. Lung ultrasound would be of minor interest if the usual tools (bedside radiography, and CT) did not have drawbacks (irradiation, low information content for radiography, and need for transportation…). Our study showed that ultrasound can be used instead of CT in many cases. Lung ultrasound is part of critical ultrasound, defined as a whole-body approach using simple machines, one universal probe, and new applications [12].

As techniques become more refined and experience increases, the lung US pattern, which was considered “artifacts,” has become an important means of evaluating pathophysiologic changes in the lungs [11].

When used dynamically, lung US is reported to be an effective means of assessing PEEP-induced pulmonary reaeration [13].

Our study used ultrasound scoring and the oxygenation method to monitor the endpoint of lung recruitment. After lung recruitment, with decreasing PEEP levels, recruited alveoli collapsed and the oxygenation level decreased. Until the endpoint, more alveoli collapsed and pulmonary parenchyma changes were aggravated, which led to dramatic changes in the air/water ratio that could be detected by ultrasound; these changes were manifested as replacing of the A line by the B line or air bronchogram consolidation inside the original B line. So that during lung recruitment, intermittent high airway pressure was first given to open the collapsed alveoli fully; this was followed by applying appropriate pressure to maintain the opening of the alveoli [14].

Choosing an appropriate PEEP is the key to maintain the alveoli open after lung recruitment. However, one feature of segment lesions in ARDS is that the lesions of the lower and dorsal lungs are severe, while those of the upper and anterior lungs are slight. The best PEEP was considered when the trapped alveoli was just expanded and the alveolar gas quantity increased by more than 20%; in addition, part of the shunt was removed, oxygenation was improved, lung injury induced by shear stress by repeated alveolar opening and closing was reduced, and pulmonary circulation was improved [15].

Considering the heterogeneous nature of morphologic changes in ARDS, it is important to establish whether lung US can show optimal changes in lung morphologic characteristics that correlate with maximal improvements in aeration. In our study, we found that the protocol for reaeration in US-guided lung recruitment was an effective means of guiding alveolar recruitment in ARDS compared with the maximal oxygenation-guided method.

The main clinical manifestations of ARDS are progressive respiratory failure and hypoxemia, which arise as a consequence of decreased lung aeration, heterogeneous alveolar collapse and consolidation, and a mismatch in ventilation and perfusion. The oxygenation index has consequently been adopted as an indicator of lung recruitment [16].

The maximal oxygenation method, based on multiple comparisons of arterial blood gas analysis, can also be influenced by a wide range of factors other than alveolar recruitment [17].

While lung US can image the entire lung tissue, the technique appears to have many of the advantages of CT for detecting dynamic changes in lung aeration, but it also is noninvasive, requires no exposure to X-rays, is straight forward, and can be performed at the bedside.

We found that lung US evaluation was a more effective means of assessing ARDS compared with the maximal oxygenation method, either for comprehensive assessment on ARDS development or searching for the recruitment end point.

First, the lung US method can describe the distribution of consolidation in an ARDS lung instead of simply indicate an oxygenation level.

Second, the significant improvement in arterial oxygenation during the 5-cm H2O PEEP trial was not consistent with the dynamic changes seen on US evaluations, which were limited to the anterior and medial lung regions.

Third, our findings have preliminary verified the protocol for reaeration in US-guided lung recruitment, which considered the lung US reaeration score as the end point and was more beneficial in guiding lung recruitment, thus highlighting the value of assessing the effectiveness of a lung recruitment strategy with lung US. Our investigation showed that the protocol for reaeration in US-guided lung recruitment, guided by the maximal reaeration score, achieved higher opening pressures and resulted in further improvements in lung recruitment compared with the maximal oxygenation method.

Last, lung US-guided recruitment improved aeration in all regions of the lung, whereas the results in the oxygenation group showed that lung heterogeneity did not improve completely, as indicated by the remaining consolidation and interstitial edema in the medial and posterior parts of the lung. On the other hand, to avoid potential hyperinflation and lung injury caused by increasing airway pressure constantly, the protocol for

reaeration in US-guided lung recruitment proposes a systematic method for achieving an optimized pressure to balance potential harm and benefits.

In our study, we found that heart rate was significantly increased and MAP was significantly decreased immediately after lung recruitment compared with basal state, and that match with study done by Tang *et al.*, between 2015 and 2017 on 40 patients with ARDS who divided randomly into two groups, group underwent lung recruitment using ultrasound (20 patients) and another group underwent recruitment using oxygenation index (20 patients) [18].

And also match study done by Grasso *et al.* on 22 patients with ARDS who were recruited from the ICUs of the Di Venere, Policlinico (University of Bari), and S. Chiara (University of Pisa) hospitals. Inclusion criteria were age more than 18 years and diagnosis of ARDS. Exclusion criteria were cardiogenic pulmonary edema (clinically suspected or pulmonary artery occlusion pressure more than 18 mmHg), history of ventricular fibrillation or tachyarrhythmia, unstable angina or myocardial infarction within the preceding month, preexisting chronic obstructive pulmonary disease, MAP less than 65 mmHg (despite attempts to increase blood pressure with fluid and vasopressors, as clinically indicated), anatomic chest wall abnormalities, chest tube with persistent air leak, pregnancy, and intracranial abnormality [19].

In our study, there was statistically significant difference between both groups as regard MAP percent change before and during lung recruitment. In lung ultrasound group, MAP decrease more significantly than in oxygenation group and that mismatch study done by Tang *et al.* and our explanation is that in lung recruitment, we reareate previously derecruited alveoli through application of an intentional and transient increase in the transalveolar pressure leading to decrease of MAP and in our study we found that in lung ultrasound group we used higher opening pressure and also higher optimal PEEP leading to more increase in transalveolar pressure leading to more decrease in venous return leading to more decrease in MAP.

In our study, we found that lung recruitment in both groups significantly increased Pao2/Fio2 ratio immediately after recruitment compared with basal state and also significantly increase dynamic compliance compared with basal state, and that match study done by Tang *et al.*, study done by Grasso *et al.*, and study done by Li *et al.* in which 12 rabbits with saline lavage-induced lung injury were randomly divided into two groups: One with alveolar recruitment guided by lung US and the other with alveolar recruitment guided by maximal oxygenation [18], [19], [20].

In our study also we found that the increase in PF ratio immediately was significantly more in ultrasound group than in oxygenation group that results match with study done by Tang *et al.* and also match with study done by Li *et al.*, [18], [20].

In our study, we found also that P/F ratio 12 h after recruitment decreased compared with P/F ratio immediately after recruitment but significantly increased compared with basal state before recruitment and also we found that the increase in P/F ratio 12 h after recruitment was more significantly in lung ultrasound group than in oxygenation group and that can be explained, as in our study, we found our optimal PEEP using lung ultrasound that was 2 cm H2O above closing pressure and we applied that optimal PEEP after recruitment and so that alveoli kept opened and not collapsed again.

In our study, we found that lung recruitment (both lung ultrasound and oxygenation group) significantly increase RV function using TAPSE compared with basal state and that match with study done by Longo *et al.* that performed on 40 anaesthetized patients with New York Heart Association class I or II, preoperative left ventricular ejection fraction at least 50% and Euro score 6 or less scheduled for cardiac surgery with cardiopulmonary bypass (CPB) and that study found that atelectasis after CPB impairs RV function but this can be resolved by lung recruitment using 10 cmH2O of PEEP [21].

In our study, we found that both opening pressure and optimal PEEP were significantly higher in lung ultrasound group than in oxygenation group and that matches study done by Tang *et al.* and also study done by Li *et al.*, [18], [20].

In our study, opening pressure was 37.28 ± 1.25 in lung ultrasound group and was 36.67 ± 0.98 and optimal PEEP was 14.64 ± 1.08 in lung ultrasound group and was 13.13 ± 0.74 in oxygenation group.

In our study, pneumothorax developed with percent 6% (three patients out of 50) in lung ultrasound group, and developed with percent 13.3% (two patients out 15) in oxygenation group with total percent 7% of all recruited patients of study (five patients out 65).

Mercat *et al.* had A multicenter randomized controlled trial of 767 adults with ALI conducted in 37 ICUs in France from September 2002 to December 2005 Comparing the effect on outcome of a strategy for setting PEEP aimed at increasing alveolar recruitment while limiting hyperinflation to one aimed at minimizing alveolar distension in patients with ALI. And that study showed pneumothorax with percent of 6.8% in recruited patients [22].

In our study, death before hospital discharge was with percent 36% (18 patients out of 50) in lung ultrasound group while was with percent 40% (six patients out of 15) in oxygenation group with overall mortality percent of all recruited patients in our study 36.9% (24 patients out 65) while in study done by Mercat *et al.*, death before hospital discharge percent was 35.4% [22].

Our study has certain limitations as is that study was single center study and we did not use CT chest to confirm lung collapse.

Conclusion

Lung US is an effective mean of evaluating and guiding alveolar recruitment in ARDS. Compared with the maximal oxygenation-guided method, the protocol for reaeration in US-guided lung recruitment achieved a higher opening pressure, resulted in greater improvements in lung aeration, and substantially reduced lung heterogeneity in ARDS.

Recommendations

- Lung ultrasound may be used to detect the lung recruitment endpoint and guide the best PEEP, as that can improve lung compliance of ARDS patients and oxygenation effect while avoiding potential hyperinflation and lung injury caused by increasing airway pressure constantly
- Further study is needed to compare sensitivity and specificity of each CT chest and lung ultrasound in confirming lung collapse.

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